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BIODIVERSITY AND THE RECOVERY OF THREATENED & ENDANGERED SALMON IN THE COLUMBIA RIVER BASIN

Recovery Issues for Threatened and Endangered Snake River Salmon
Technical Report 8 of 11

Technical Report 1993

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BIODIVERSITY AND THE RECOVERY OF THREATENED AND ENDANGERED SALMON SPECIES IN THE COLUMBIA RIVER BASIN

Recovery Issues for Threatened and Endangered Snake River Salmon
Technical Report 8 of 11

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EXECUTIVE SUMMARY

It is the stated purpose of the Endangered Species Act "to provide a means whereby the ecosystem upon which endangered species and threatened species depend may be conserved." Conservation of the Columbia River ecosystem and the diversity of gene pools, life histories, species, and communities that comprise it, should become a major objective of species recovery and fish and wildlife management programs in the Columbia River Basin. Biodiversity is important to both species and ecosystem health, and is a prerequisite to long-term sustainability of biological resources. In this paper, I provide an overview of various approaches to defining, measuring, monitoring, and protecting biodiversity. A holistic approach is stressed that simultaneously considers diverse species and resource management needs. Emphasis is on threatened and endangered species of salmon and their associated habitats.

Biodiversity can be organized into compositional, structural, and functional categories; within each category, management opportunities and risks can be identified at different levels of biological organization . The Columbia River Basin comprises an enormous variety of ecosystems and associated biological communities that are undergoing continual change in response to natural and human disturbances. Species are being lost, replaced by non-native species, and introduced or supplemented in increasing numbers. Current trends in habitat degradation (including terrestrial components) and fragmentation must be reversed if salmon are to persist into the future.

General guidelines are identified for species recovery and ecosystem conservation. The need to launch a program to inventory, monitor, and assess biological resources for conservation purposes is paramount. Research into the basic ecology of riverine biota is needed, as are better techniques for quantifying biodiversity through the use of indicator species, processes, and spatial units. Consideration should be given to establishing a basin-wide preserve system that guarantees protection of critical habitats and the perpetuation of naturally functioning systems.

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1. INTRODUCTION

Dams, forestry practices, agriculture, and other human activities have altered the natural dynamics of the Columbia River, yet it continues to support a divers,e biological community that has considerable economic and aesthetic value. Some of the more obvious physicochemical impacts include altered water temperature and flow regimes, modified hydraulics, and increased sediment and pollutant loading from a variety of point- and non-point sources. By his actions man has introduced several species, allowed some to go extinct, and altered the abundance and distribution of those that remain. The river and its biota will undoubtedly undergo further change as the human population within the basin grows and places increasing stress and demand on its resources.

Resource management within the Columbia River Basin has been propelled historically by economic forces, the product of increasing demand, changing technologies and values, and policies administered by a variety of federal, state, and private entities. Emphasis has been on developing the river's hydropower and agricultural water supply potential, minimizing flood hazards, and improving navigation and recreational opportunities. Taken together, man's activities have had less than desirable consequences in terms of protecting environmental values - ecological, scenic, and cultural. Environmental management has been essentially by trial and error, narrow in focus, and event driven, as exemplified by recent listings of several stocks of Snake River salmon as threatened species under the Endangered Species Act (ESA, Act). Attempts to balance economic and (traditionally held) non-economic values have been unsuccessful in the past, but may improve under the impetus gained from the development of recovery plans.

Debate over the best ways to utilize the abundant yet finite supply of water conveyed by the Columbia River and its tributaries has intensified in recent years in response to extended periods of drought, declines in once abundant stocks of salmon, and increasing environmental activism among various interest groups. The threat of extinction of Snake River sockeye salmon, their numbers having dwindled to a few fish, is a prospect that any number of species will face unless effort and expense are made to avert further decline. Species most immediately threatened with extinction are those which are susceptible to commercial exploitation, competition and predation by exotics, and habitat perturbation.

In this paper we consider the need for preventing further species declines and extirpations. It is our contention that the most practical, cost effective, and dependable means of protecting individual species within the Columbia River system is to adopt a holistic approach to management that seeks to maintain a high degree of biological diversity over space and through time. Biological diversity, or biodiversity, refers to the natural variability, from the genetic through species and ecosystems, that underlies biological form and function. We will discuss the importance of biodiversity to species recovery and ecosystem health, along with practical ways of maintaining it, as a prelude to suggesting priorities for research and management. Our main point is this: species recovery and longer-term management priorities should acknowledge the fundamental importance of maintaining biological diversity within the Columbia River ecosystem. Maintaining diversity at all levels, but particularly at the ecosystem level, will facilitate the recovery of currently threatened species and is the surest way of avoiding the loss of other species in the future.

2. SOME FUNDAMENTAL QUESTIONS

The immediacy of the threat of extinction of “charismatic” species such as the Snake River races of sockeye and chinook salmon has forced us to consider a variety of short-term options for their protection, but in the long run species extinctions will be most easily avoided by maintaining a diverse and stable aquatic community. Ecosystem integrity or diversity is emphasized because (1) the entire Columbia River basin is under threat, (2) protecting the ecosystem will afford protection to most of the species present, (3) we lack specific knowledge of the amount and significance of diversity at the level of species and below, and (4) the most effective management tools available - manipulations of river flow and space (area and volume) - affect entire communities over large areas. Just what particular forms or processes constitute a healthy Columbia River ecosystem awaits further definition, but because individual species require functioning ecosystems to survive, their protection and recovery must be viewed within the wider context of ecosystem conservation (Saunders et al. 1991).

Before turning from single species management issues to ones concerning multiple species, some basic questions need to be raised: Why are we trying to prevent the extinction of these particular species? What are we trying to recover? What priority does recovery have within the larger context of ecosystem management? These questions have moral and ethical dimensions (which we will skirt), but within the narrow context of the ESA, the answers are that we want to prevent extinction for economic, aesthetic, and scientific reasons; we are trying to restore populations to viable size; and we are compelled to give threatened and endangered species priority over competing demands by the injunctions of the Act.

Is it reasonable to ask whether great sacrifices should be made to prevent one or a few species from going extinct? After all, if evolution and extinction are natural processes, why go to inordinate lengths to protect a handful of species? The answer is that not just one or a few species, but entire evolutionary lineages are threatened. Environmental changes today are of an origin and magnitude never seen before and to which most species are unable to respond to through adaptation. Habitat degradation, especially, is accelerating (Soule and Kohm 1989).

If one accepts the premise that the best way to avoid further species loss is to maintain biodiversity, the two most important questions are “What kinds of biodiversity do we want?” and “How do we create, maintain, or enhance that diversity?” One of the objectives of this paper is to identify different types or levels of biodiversity and discuss their relative importance relative to species recovery and long-term persistence. We identify the need and some of the methods available for measuring, restoring, and conserving the diversity of listed species and their associated habitats. Where possible, we contrast single species recovery with the larger, and potentially contradictory, goals of maintaining biological diversity and ecosystem integrity, focusing on problems that researchers and managers may find useful to address.

3. BIODIVERSITY DEFINED

Biological diversity has been defined as "the variety and variability among living organisms and the ecological complexes in which they occur" (Offrce of Technology **Assessment 1987). The** term is most commonly used to refer to the number, frequency, and types of **species present** within a given geographical area This information is critical but insufficient to describe the full diversity of living organisms, their associated habitats, and the processes that sustain them.

In this paper we define biodiversity to include the following levels of organization: genetic, life history (i.e., intra-population variability), population-species, community, and ecosystem (Table 1). Each level of organization is defined by its constituent parts, but also has attributes that are unique to that particular level. Noss (1990) identified three attributes that are common to all levels: composition, structure, and function (Figure 1). Drawing from Franklin (1988), Noss (1990) summarized these attributes as follows:

> "Composition has to do with the identity and variety of elements in a collection, and includes species lists and measures of species diversity. Structure is the physical organization or pattern of a system, from habitat complexity as measured within communities to the pattern of patches and other elements at a landscape scale. Function involves ecological and evolutionary processes, including gene flow, disturbances, and nutrient cycling."

We will address several types of biodiversity associated with each attribute, especially levels relevant to the recovery of listed stocks and to the larger Columbia River ecosystem: genetic, life history, population, species, and community.

3.1 *GENETIC* DIVERSITY

The molecular structures and processes that code for heredity form the most basic level of biological organization. Maintenance of *genetic diversity* is recognized as prerequisite for the long-term survival of a species because the loss of this diversity has been associated with reduced fitness and lowered adaptability. The exact amount of variation necessary to maintain population viability is unknown and probably varies among species. Nevertheless, theory and experience tell us that genetic risks are most acute when numbers of breeding animals become very small, non-compatible genetic types enter (primarily through introductions) the breeding population, and selection regimes favor genotypes that may be well-adapted to "unnatural" conditions (e.g., hatchery environments) yet unable to survive in the wild (Kapuscinski and Miller 1992).

Population bottlenecks increase the probability of genetic drift and inbreeding. Both processes result in the loss of genetic variation; inbreeding also tends to increase the frequency of deleterious alleles due to interbreeding among closely related individuals. Small populations are more susceptible to loss of genetic diversity and identity resulting from outbreeding depression (lower fitness caused by mixing of non-compatible genetic systems) and hybridization (introgression with other species) (Moyle and Sato 1991).

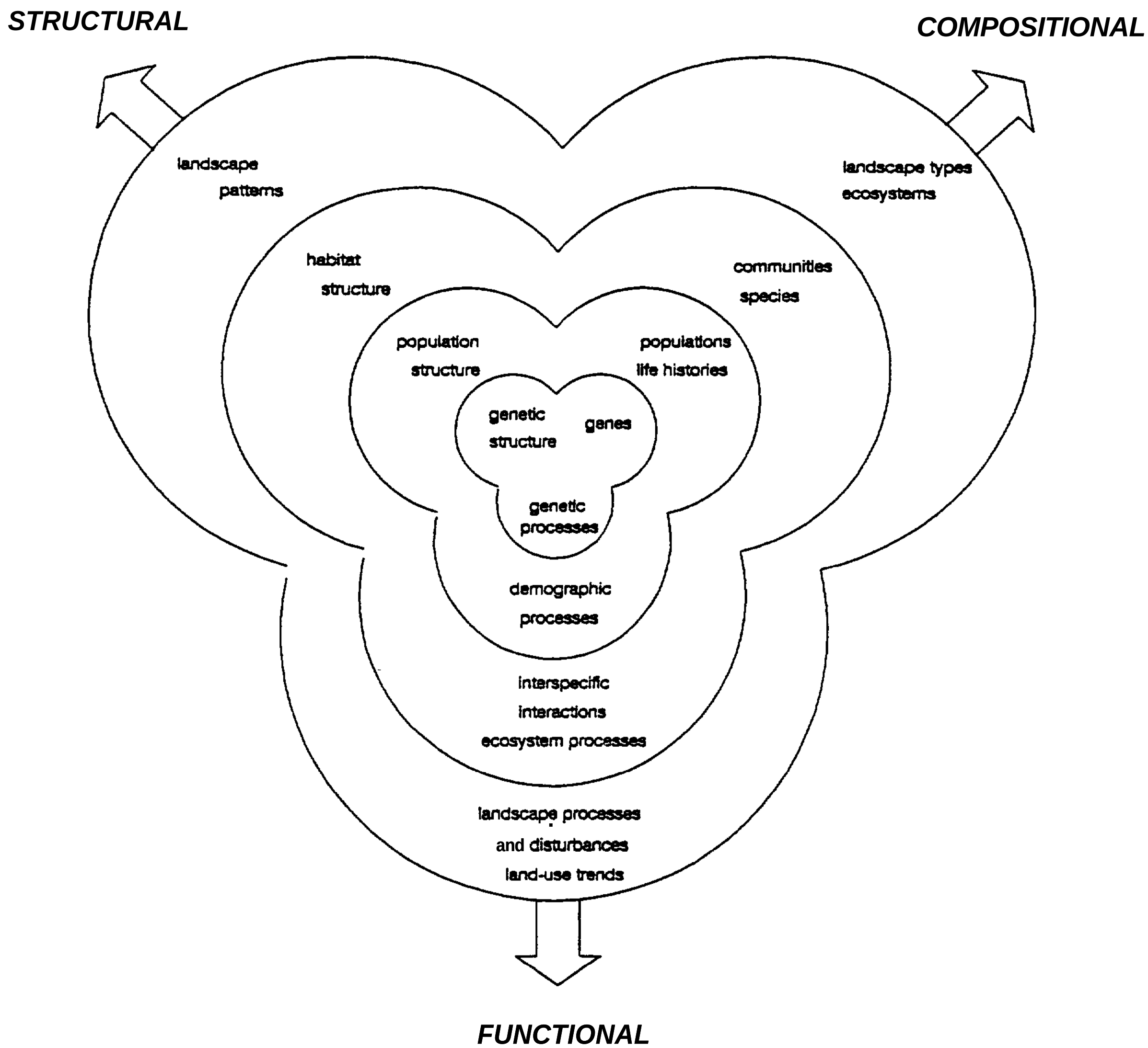

Figure 1. **Organization of different levels of biodiversity along compositional, structural, and functional dimensions (after Noss 1990).**

Table 1. Major attributes and processes at different levels of biodiversity.

Level of Organization	Important Characteristics
Genetic	Heterozygosity, allelic diversity, polymorphism Variability among individuals, populations, and species Uniqueness (presence of rare alleles) Adaptability, heritability Historical trends Selection pressures (type and intensity) Mutations, gene flow Genetic drift, inbreeding Co-adaptedness Hybridization
Life History	Variety and variability Genetic vs. environmental control Phenology Historical vs. current patterns Resource requirements and specificity Physiological ecology Bioenergetics
Population - Species	Taxonomic status Adaptation and acclimation Evolutionary legacy Metapopulation structure and size Spatial distribution (range, inter-population distance) Ecological status Life history diversity Cohort variability Human intervention (fishing, stocking, eradication)
Community	Species composition (endemism, exotics, rarity) Species diversity (richness, speciation) Persistence and resilience Biomass, productivity Resource partitioning Trophic structures Deterministic vs. stochastic processes Functional guilds Multiple species dynamics Predation and competition Disease and parasites Mutualistic interactions

Table 1. continued

Level of Organization	Important Characteristics
Ecosystem	Climatic and geologic influences Water and nutrient cycling Soil chemistry and physics Primary and secondary production Energy flow Stability Microhabitat and patch dynamics Disturbance patterns and frequency Human impacts

Loss of genetic diversity and identity, whether through decreases in population size, hybridization, or artificial selection, limits both management options and evolutionary flexibility (Echelle 1991). Because threatened or endangered species status implies small population size, and because recovery is likely to involve some form of artificial propagation, *there* is a high risk of reduced genetic variation among salmon stocks currently protected by the ESA.

Protein electrophoresis has been extensively applied to study genetic variation within and among populations of Pacific salmon of the Columbia River (see studies cited by Steward and Bjomn 1990). Electrophoretic samples of Snake River chinook salmon populations have been analyzed and reported by Winans (1989), Utter et al. (1989), Waples et al. (1991) and Marshall (1992).

Three measures of genetic variation are typically derived from electrophoretic data: heterozygosity, the average frequency of heterozygotes per locus per individual; allelic diversity, the mean number of alleles per locus, expressed as a percentage of the alleles originally present; and polymorphism, the proportion of loci having two or more alleles. Of these, heterozygosity is the more reliable index of genetic variability because it is relatively insensitive to sample size (Echelle 1991).

Genetic diversity in salmonids and other species composed of sub-populations can be broken down into intra- and inter-population components. Chakraborty and Leimar (1987) discuss sampling designs and hierarchical analyses that can be used to partition genetic variation into its component parts; Echelle (1991) provides examples for salmonids and several species of threatened fishes of western North America.

One would expect, *aprioti,* extensive genetic variation among Pacific salmon populations because of the diversity of environments in which they are found, and because adult salmon return with remarkable fidelity to their natal streams to spawn. Electrophoretic studies have strongly supported the view of salmon species as composed of numerous more-or-less isolated and genetically distinct populations. This, in turn, has led to the definition of Pacific salmon “species” under the ESA to include any “Evolutionarily Significant Unit” (ESU; Waples 1991). The ESU standard recognizes that protection afforded by the ESA should include maintenance of the genetic variability contained within the population structure (Hard et al. 1992).

Under the influence of ideas and findings of fisheries geneticists (cf. Allendorf et al. 1987), resource managers in the Columbia River Basin have generally embraced the goal of maintaining genetic resources of individual species of Pacific salmon. The Northwest Power Planning Council is considering adoption of the following genetic resource conservation goal: “To maintain genetic resources of salmon and steelhead in native, naturalized, and artificially propagated populations with no avoidable and irreversible losses of genetic diversity resulting from management interventions or inactions” (Riggs 1990). Various planning, monitoring, and evaluation proposals have been advanced to ensure that this goal has been met (Currens et al. 1990; Genetic Evaluation Group 1992).

Threats to a species’ genetic diversity can be reduced by maintaining the genetic integrity of discrete populations, increasing effective population sizes, avoiding selective breeding, replicating populations to guard against catastrophic loss, and monitoring genetic resources to warn of undesirable changes. It is important to delineate and conserve ESUs based on a thorough knowledge of the natural distribution of genetic diversity. Federal, state, and university scientists should continue to apply electrophoretic and DNA techniques to discriminate among different salmon populations, ascertain levels of genetic diversity, monitor the effects of supplementation programs, and resolve mixed-stock fisheries. Although important strides have been made in defining population structures, more sampling is needed to better define genetic relationships and geographic limits. As it is, there is considerable uncertainty as to the significance of observed genetic patterns (Currens et al. 1990). Another unresolved issue is whether genetic diversity as measured by electrophoresis or DNA techniques is correlated with individual or population fitness. We need more information on how much genetic change or gene flow is “normal”, given that straying among Pacific salmon is common. If hatchery propagation is to be used as a recovery tool, we need to clearly identify genetic objectives, risks, protocols, and contingencies for reducing risks. Kapuscinski et al. (1990) and Currens et al. (1990) discuss ways of integrating genetic concepts and safeguards into hatchery design and operational plans.

3.2 LIFE HISTORY VARIATION

Less attention is usually paid to life history variability than to other types of biological diversity. This is unfortunate since species - salmonid populations in particular - are not solely assemblages of similar individuals but rather as composites of one or more groups of fish whose life cycles describe unique “trajectories” in time and space. A *life history type* has been defined as a succession of life stages that collectively exhibits a unique pattern of movement and distribution within the environment (RASP 1993). It is through life history variability that salmon are able to efficiently exploit different habitats and take advantage of seasonal and spatial variations in resource availability, thereby reducing intraspecific competition and increasing overall fitness. A diversity of life history types also serves to buffer the population against environmental unpredictability. If critical habitats are destroyed or altered, the affected life histories are not likely to persist within the population matrix.

If the physiological or behavioral traits that distinguish one life history from another have a genetic basis, and if they enhance the fitness of individuals possessing those traits, then natural selection will favor that life history type. Although certain life history characteristics may be inherited and reflect adaptation to local conditions, it would be premature and probably incorrect to assert that the entire array of behaviors observed in salmon is genetically controlled. Variability in life history may result, in part, from spatial and temporal variation in growth opportunity among geographic areas. Age-at-smolting among Atlantic salmon, for example, depends on fish attaining a genetically determined size threshold; environmental conditions determine when that threshold is reached (Thorpe et al. 1992) . Density-dependent mechanisms influence not only growth but, to varying degrees, the behavior of fish. Behavioral changes may alter population selection pressures or the probability of extinction (Taylor 1991). Until our understanding of the interaction between genes, the environment, and life history variation improves, it would be prudent to measure, preserve, or enhance both genetic and life history diversity.

A wealth of basic life history data, exist in agency files and reports, but little effort has been made to systematically compile, review, and use this information to classify and protect salmon populations within the Columbia River. Notable exceptions include Howell et al. (1985) and Schreck et al. (1986), who identified several life history characteristics (e.g., time of entry into freshwater and time of spawning) on a stock-by-stock basis. More recently, life history information currently available for Snake River sockeye and chinook salmon, and lower Columbia River coho salmon was submitted and evaluated by the National Marine Fisheries Service as part of ESA status reviews conducted for these species (Johnson et al. 1991, Matthews and Waples 1991, Waples et al. 1991).

3.3 SPECIES DIVERSITY

Various criteria have been used to delimit species, including morphological discontinuity, interbreeding ability and reproductive isolation, relationships of ancestry and descent, ecological adaptation, and genetic cohesion (Rojas 1992). For ESA purposes, a species is “any distinct population segment...which interbreeds when mature” (ESA, Sec. 3(15)). The National Marine Fisheries Service has interpreted this to include populations of Pacific salmon that are “distinct” by virtue of their reproductive isolation and relative importance in the evolutionary legacy of the species (Waples 1991). Implicit in this definition is the recognition of populations as evolving entities, capable of responding to continually changing selective pressures. To avoid confusion in the use of the terms species, population and ESU, we refer to Pacific salmon species in the traditional taxonomic sense; that is, as members of the genus Oncorhynchus. Species of salmon native to the Columbia River consist of local populations which interact to varying degrees via straying and interbreeding. We restrict our use of the term ESU to those populations of salmon currently listed as threatened or endangered species.

Within-species or population diversity can be viewed in terms of the number of distinct populations within a geographic area. Area boundaries may be somewhat subjective but typically delineate obvious physical or reproductive discontinuities. For example, the Snake River Basin is one of several spatial units which comprise the range of spring chinook salmon within the Columbia River Basin (Matthews and Waples 1991).

3.4 COMMUNlTY DIVERSITY

A "community" can include all taxa present within an area, or it can be restrictively qualified by habitat type, taxonomic group, or similarity in function. For example, in the Columbia River separate communities can be described for riverine/lotic and reservoir/lentic habitats. Alternatively, one can distinguish between periphyton, phytoplankton, zooplankton, benthic invertebrate, and fish communities. Macroinvertebrate and fish communities are frequently partitioned into functional types. Grossman et al. (1982), for example, partitioned the fishes from a midwestem stream into trophic guilds in order to better describe community structure and function.

The traditional method of assessing community structure has been the use of species diversity or similarity indices (e.g., Simpson 1949). Community diversity is indexed by the number of species and their relative contribution to total numbers or biomass in an area (species richness). Less commonly, community diversity refers to the number of higher taxa, such as families, orders, or phyla, within a geographical area (Moyle and Leidy 1992).

Assessments of community diversity and the prospects for recovery of listed species of salmon should include interspecific interactions such as competition, predation, and disease. The complexity and strength of ecological processes that determine community structure and production also affect the persistence of its constituent species (Moyle and Sato 1991). For those attempting to describe compositional and functional attributes at this level, key questions should focus on diversity, persistence, stability, resiliency, productivity, and rates of species loss and replacement.

3.5 ECOSYSTEM DIVERSITY

"A window into the future is the past..."

Biodiversity at the ecosystem level integrates biological structure and function with the various natural and anthropogenic factors that cause them to change. Free-flowing rivers are open, linear systems, regulated rivers less so, but both are influenced by events that occur outside of their channel boundaries. It is important to apply a landscape perspective to understand how and to what extent the Columbia River aquatic ecosystem is affected by adjacent and upstream terrestrial environments. Less obvious in some respects but equally important to consider are the biological and physical changes that have occurred over time. Historically, the Columbia River possessed a set of biophysical characteristics that were the product of local geology, climate, and natural disturbances. Man's activities have altered natural patterns of runoff, temperature, water chemistry, and habitat structure. These fundamental characteristics must be deduced from historical data or theoretically reconstructed if current ecosystem status is to be understood, future probable states predicted, and appropriate management prescribed. The choice of temporal scale will affect the interpretation of observed patterns of biodiversity. We will discuss various spatio-temporal linkages in contrasting the biological properties of the Columbia River under pristine (unregulated) and contemporary (regulated) conditions.

4. THE COLUMBIA RIVER ECOSYSTEM: HISTORICAL VS. PRESENT STATUS

Before turning to the subject of biodiversity in today's Columbia River, it would be useful to briefly review the physical and limnological changes expected as a river is altered from a free-flowing to an impounded environment. Depending on the number and kinds of dams in place, river regulation alters the hydrological and geomorphological dynamism of the natural system. Flow patterns and water quality change, impoundments are created, and habitat within the remaining lotic reaches is altered (Table 2). Impounded sections of the river take on lake-like characteristics, with vertical as well as longitudinal and lateral dimensions. The movement of water and suspended materials is less unidirectional in regulated rivers than it is in unregulated rivers (Baxter 1977, Boon 1992).

Many of the environmental changes caused by dam placement along the Columbia River mainstem are consistent with the "serial discontinuity concept" (Ward and Stanford 1983). The primary impacts of dams on the flow of material and energy through the system appears to have been the interruption of sediment transport processes, increased organic matter processing and nutrient retention, disruption of migration patterns due to physical and thermal barriers, and extensions of lower river production dynamics into impounded reaches upstream.

From their analysis of collection records stored at Oregon State University, Li et al. (1987) derived the historical fish composition of a "generalized Pacific Northwest river system" which may be considered representative of the Columbia River fish community under pristine conditions. The authors described a native fish assemblage dominated by salmonids (39 - 50%) and sculpins (20 - 30%). The fish fauna were predictably structured along a longitudinal continuum, with species added and/or replaced as river gradient decreased, and temperature and cross-sectional area increased. Species (fish) diversity increased in a downstream direction in response to increased niche diversity (e.g., substrate and food sizes) while headwater specialists gradually dropped out. Fish living in headwater reaches tended to be stenothermic, trophic specialists, whereas downstream fish species were progressively eurythermic and trophic generalists, typically omnivores or large invertebrate-fish predators. Although they are neither exhaustive nor specific to the Columbia River system, we reproduce in Table 4 the generalized lists of native and introduced fish species of the Pacific Northwest compiled by Li et al. (1987). Fish are grouped by thermal guild.

Native fish species in the Columbia River evolved under conditions in which stochastic forces apparently played a greater role in determining community structure and species abundance than did biological determinism (i.e., density-dependent mechanisms and other biologically mediated processes). Fish related then as now to the quality, quantity, and stability of the environment. The environment was not temporally stable, but periodically experienced catastrophic floods and droughts that acted as biological "reset" mechanisms. The "intermediate disturbance hypothesis" suggests that species diversity should generally be highest at moderate intensities or frequencies of disturbance as long as abiotic factors do not eliminate species or permit a few species to completely dominate through competition, predation, or other means (Connell 1978, Hobbs and Huenneke 1992).

Table 2. A comparison of physical and limnological characteristics of free-flowing and impounded sections of the Columbia River (based in part on Ryder and Pesendorfer 1989).

Attribute	River	Reservoir
Erosion and deposition	Flow-induced teporally variable, extensive, strong horizontal and longitudinal gradients but generally in equilibrium; non-point sources	Flow- and wave-induced, near-shore and in-channel, less extensive, locally uniform, aggradational; trap sediments; affected by dredging and levee construction
Substrates	Heterogeneous, larger mean particle size, decreases downstream, unstable	Smaller and more uniform, size decreases with depth, temporally stable
Channel shape	Linear, narrow, meandering, trapezoidal, shallow but locally variable depths	Linear to ovoid; wider, bowl-shaped in cross-section, relatively deep and uniform
Ice formation and scour	High	Low
Flow characteristics	Primarily unidirectional; gravitational; locally variable depending on channel form and bed material; discharge and stage temporally variable; subject to out-of-channel flooding; Downstream oriented, locally uniform, but more three-dimensional; greater die1 but less temporal variability overall in flow and water elevations; diminished flood effects	
Temperature	Strong die1 and seasonal fluctuations; non-stratified, non-buffered (e.g., air temperatures, shading)	Buffered but still variable over time and space; slower response times; higher maxima; weak stratification
Chemicals and nutrients	Well-mixed, high nutrient throughput, low biological processing	More stratification; greater retention and attenuation, some biological mediation

Table 3. A comparison of ecological atttibutes affecting the biodiversity of free-flowing and impounded sections of the Columbia River (based in part on Ryder aud Pesendorfer 1989).

Attribute	River	Reservoir
Energy and nutrient sources	Primarily detrital input via tributaries, low retention and uptake, autochthony and efficiency increase in downstream direction	More internal primary production and cycling, slower turnover, occasional limitation
Riparian vegetation	Strong biological impacts	Little effect
Primary production	Low, periphyton dominated	Low, primarily planktonic, some periphytic and macrophytic production
Zooplankton	Production and diversity are low, increasing downstream	Higher production and diversity
Invertebrates	Diverse headwater communities; more homogeneous and productive downstream	More near-shore diversity; adapted to finer substrates and lower dissolved oxygen levels
Fish adaptations and resource requirements	Specialized and numerous adaptations; strong niche partitioning	Numerous adaptations but more overlap and ecological plasticity
Fish production	Low	Intermediate to high
Fish community structure	Stochastic; temporally variable, longitudinal zonation	Deterministic, stable, quasi-harmonic
Community fragility and resilience	High, rapid colonization and recovery	Buffered, slower recovery
Ecological diversity	Intermediate	High

Table 4. **List of fish species of the Columbia River compiled from historical and recent surveys (adapted from Li et al. 1987).**

Native Species	Introduced/Invader Species
Stenothenns	
Lampe tra richardsoni *L. ayresi* *Cotus beldingi* *C. marginatus* *C. bairdi* *c. cognatus* *c. gulosus* *C. confusus* *C. aleuticus* *C. rhotheus* *Catostom us catastom us* *C, platyrbnchus* *Lota Iota* *Spirinchus thaleichthys* *Thaleichthys pacificus* *Oncorhynchus nerka* *0. kisutch* *0. tshawytscha* *0. mykiss* *0. clarki* *Salvelinus confluentus*	*Conegonuys clupeafonn is* *Salvelinus fontinalis* *Salmo tiutta*
Mesotherms	
Lampetm tridentata *A cipenser tmnsmontanus* *A. medits tris* *Cottus perplexus* *C. asper* *Catostom us colum bianus* *Mylocheilus caurinus* *Novum bm hubbsi* *R hinich thys catamctae* *R. falcatus* *Percopsis tmnsm on tana*	*Stizostedion vitreum vitreum* *Moreone saxatilis* *Esox lucius* *Perca flavescens* *Micropterus dolom ieui*

Table 4. continued

Native Species	Introduced/Invader Species
Eurythems	
Rhinicthys osculus *A crvcheilus alutaceus* *Catostom us macrocheilus* *Cousius plum beus* *Ptychocheilus oregonensis* *Gasterosteus aculeatus* *Riochardsonius balteatus* *Hybopsi scram eri* *Gila bicolor*	*Notuus gwinus* *Ictalurus punctatus* *I. nebulosis* *I. melas* *I. natalis* *Cyprinus car@0* *Tinca tinca* *Pylodictus olivaris* *Carrasius aumtus* *Lepomsis gibbosus* *L. cyanellus* *L. gulosus* *L. macrochinrs* *L. nigromaculatus* *Microptenrs salm oides* *Gam busia #finus*

In reality, the Columbia River system encompassed both headwater areas in which background levels of disturbance and resource availability severely limited species diversity, and downriver reaches in which the biological community was subjected to less organizational distortion, both seasonally and from year to year. Thus, both environmental unpredictability and biological accommodation were important in shaping the aquatic community.

Li et al. (1987) rightfully pointed out that overharvest of salmon and sturgeon from the Columbia River in the late 1800s - early 1900s had significant ecological impacts, enough so that the absolute causality of later dam-related effects on the abundance of these species is not clear cut. The diversion of water for agricultural purposes, and increased nutrient and sediment inputs that resulted from the expansion of land use in the basin may also have altered the community structure before most of the mainstem dams were built. These impacts notwithstanding, the most profound changes in the Columbia River ecosystem may be traced to the construction and operation of dams along its tributary and mainstem reaches. Between 1930 and 1975, the number of dams constructed within the Columbia River basin increased exponentially to over 100 facilities (Li et al. 1987).

The dams and associated impoundments on the Columbia River caused changes that extended in up- and downstream directions. The most dramatic impacts on native salmon stocks resulted from high head dams that prevented access to headwater spawning and rearing grounds. Widely cited examples include the elimination of salmon and sturgeon from the Snake River drainage above

Hells Canyon dam, and from the Columbia River upstream of Grand Coulee Dam. Although downstream dams were equipped with a variety of fish bypass facilities (ladders, locks, lifts, and collection and transportation facilities), mortality on fish migrating in either direction has been a recurring problem due to powerhouse operations and the difficulty of locating diversion/attraction structures and entrances at proper locations. Another source of dam-related mortality that required remediation was the occurrence of biologically harmful levels of dissolved gases that were entrained in water as it plunged over mainstem dam spillways. Injuries and deaths caused by gas bubble trauma were common during high flow years in the early 1970's. The seriousness of the problem was reduced after structural changes were made at the downstream face of the dams (Ebel and Raymond 1976).

Reservoirs located behind Columbia River dams possess characteristics that range from riverine to lacustrine, depending on local river gradient, dam height, and mode of project operation. Although all of the lower Columbia and Snake River dams are run-of-river projects, their reservoirs support fewer native fishes because the lake-like conditions favor other species of fish. Biological responses to habitat modification have included the loss of certain native species, an increase in abundance of others, and colonization by non-native species (Table 4). Many of these species were introduced. Li et al. (1987) suggested that the fish fauna of Columbia River reservoirs bear a greater resemblance to those of Midwestern lakes than to the original river. Nevertheless, it is important to point out that although the number of species (as well as total fish production) in Columbia River reservoirs exceeds the number that inhabited the original river at the same location, a large proportion of the native fish fauna is still intact. The present fish assemblage can be characterized as one containing disproportionately large numbers of non-native species and smaller numbers of native species. Species or populations that have declined, been displaced, or gone extinct were those which were susceptible to commercial exploitation, competition and predation by exotics, or habitat perturbations. Local endemics limited to swift, comparatively shallow-river habitats, species with limited reproductive capacities, and species that migrated long distances were vulnerable (Li et al. 1987, Moyle and Leidy 1991).

It is not uncommon to observe increases in species richness in regulated rivers. Reservoir biota are subjected to few cataclysmic stresses, yet disturbances are usually frequent enough to permit coexistence of a diverse assemblage of generalist and specialist species (Ryder and Pesendorfer 1989). In the Columbia River, the kinds and types of disturbance caused by man's activities, especially those related to the operation of mainstem dams, have maintained astatic fish communities (see Ryder and Kerr 1978). Biological equilibrium has not been reached. More populations and species will go extinct either through random population fluctuations or through loss of genetic diversity if the current disturbance regime is maintained.

What can be done to prevent further species losses, rebuild already depleted populations, and still maintain desirable attributes of the Columbia River ecosystem?

5. THE IMPORTANCE OF CONNECTIVITY

For salmon and other migratory species, it is important that habitats used by different life stages or components of the population remain accessible (Meffe and Vrijenhoek 1988) and that opportunities for genetic exchange via individuals moving among populations be maintained. A certain level of habitat quality, accessibility, and geographical connectivity are necessary for a migratory species to persist. Mainstem dams, inadequate flows, and fragmentation resulting from habitat degradation and loss have disrupted migratory movements between freshwater and marine habitats, cut populations off from other populations and formerly occupied habitats, confined populations to increasingly smaller areas, and changed the composition of life history types within populations (Moyle and Sato 1991).

Although they remain in freshwater throughout their life cycle, populations of cutthroat trout and bull trout in tributaries to the Columbia River are affected by habitat fragmentation in much the same way as anadromous species. As land use in the upper basin has increased, the availability of suitable habitat and the size of areas occupied by resident fish has decreased, so that, for example, formerly ubiquitous populations of native cutthroat trout in Idaho are now restricted primarily to headwater streams (Figure 2; Rieman and Apperson 1989). As cutthroat populations become isolated from one another, they become increasingly susceptible to external events and factors that pose an increased threat to small, isolated populations. Opportunities for genetic exchange and recolonization are diminished. Other species are at varying degrees of risk depending on the cause and extent of isolation, relative to their habitat requirements and mobility. Biological diversity will decline if extinction or emigration are not balanced by habitat restoration, restorative immigration, or intentional replication of populations.

Clearly, there are areas within the Columbia River Basin that are as yet unspoiled and still support viable communities of native species. Most are in headwater reaches. Without careful management, these refuges will become more and more like the degraded areas surrounding them. Steep spatial gradients in habitat quality and resource availability are extremely important to anadromous fish or other species that are sensitive to external inputs or migrate across refuge boundaries. If external conditions are not conducive to survival, then it makes little difference how good conditions are within the refuges.

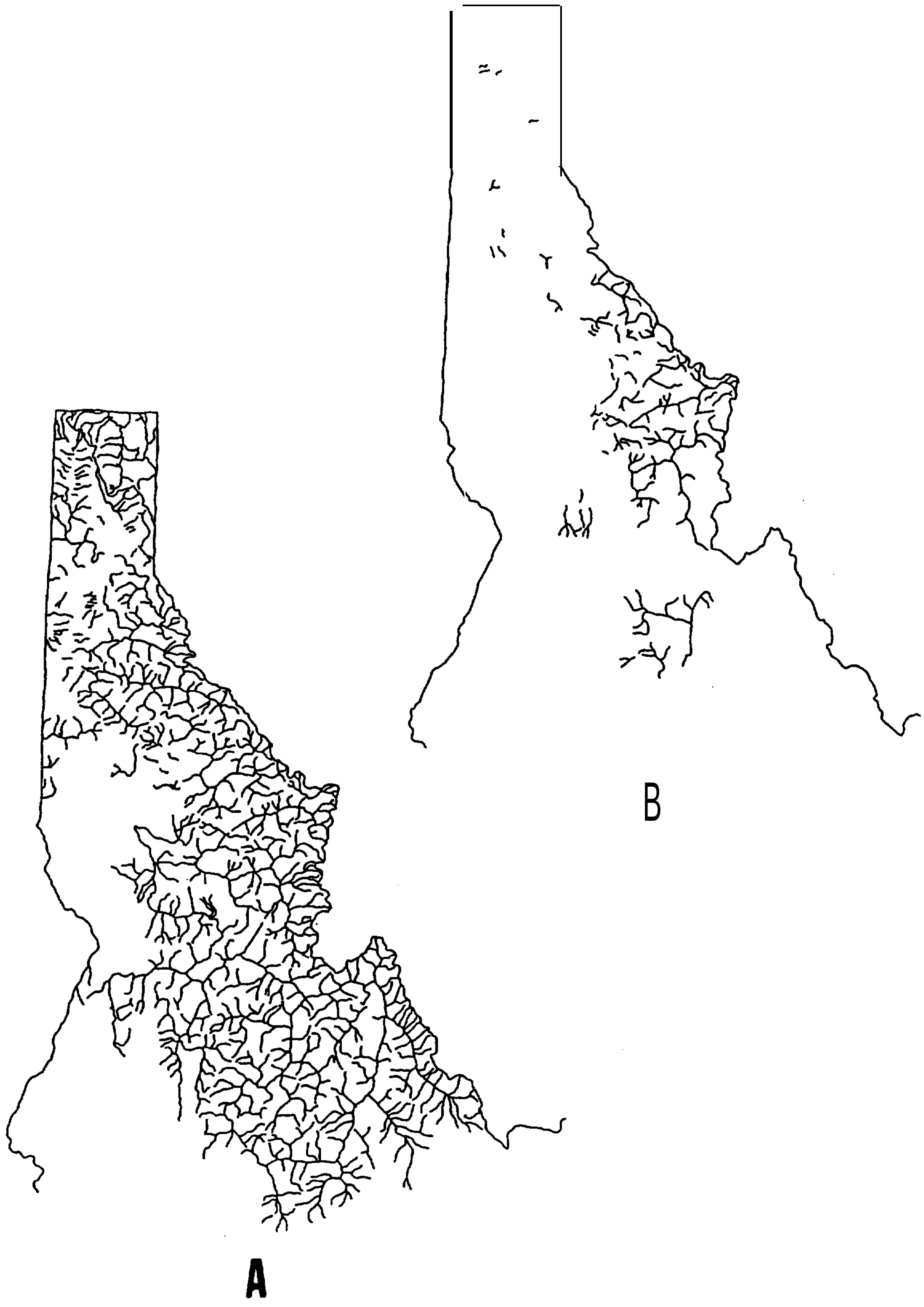

Figure 2. Historical (A) and current (B) distribution of cutthroat trout populations in Idaho streams (from Riemau and Appelson 1989).

6. RESEARCH, MANAGEMENT, AND CONSERVATION

An overriding goal of a recovery program for listed stocks should be to prevent further erosion of genetic, life history, and inter-population variability until downward trends in survival, productivity, and population size can be reversed. To do this, a better understanding is needed of existing diversity - genetic variability, life history types, and populations; their patterns of distribution and abundance - within the Columbia River system. We also need to understand how diversity is maintained naturally, and how it is related in a general sense to population viability and risk of extinction. From this knowledge, we will be able to more accurately predict the consequences of our management actions.

Species recovery plans should also acknowledge the need to maintain biodiversity at community and ecosystem levels. Managers can choose from several options: (1) accept the status quo (i.e., progressive loss of native populations and species), (2) maintain the existing system with no further loss of native species, (3) reconstruct the historical ecosystem, or some semblance of its community structure, or (4) manipulate conditions to achieve some desirable future state. Before proceeding, we must clearly articulate our objectives and establish priorities for management.

Given man’s propensity to modify natural systems, both by design and happenstance, we can expect the Columbia River system to remain nonequilibrial in the future. Managers should therefore remain flexible, responding to and in some cases actively promulgating change through direct intervention. There will be opportunities to not only prevent further loss of diversity but to reintroduce lost diversity at different levels. We discuss in a later section some of the tools that might be used to achieve these objectives.

Comparatively little attention has been given to less conspicuous species, many of which are threatened with extinction, that are indigenous to the Columbia River Basin. We should ask ourselves whether we are being short-sighted in our neglect of these species; whether they can be adequately protected under the umbrella of measures presently contemplated for a small number of “high profile” species. By forcing us to manage for the recovery of individual species, the ESA presents a difficult problem: steps taken to ensure the recovery of a few select species may be contrary to the more general goal of maintaining overall species diversity. Depending on the measures implemented, some species will win and others will lose. If the sole intent is to minimize the immediate risk of extinction of Snake River salmon populations, then money and effort can be spent with little consideration given to other species. Even if negative impacts are anticipated, they may be deemed tolerable if limited to non-native pest species. The choice is more difficult if it is likely to adversely affect other economically or ecologically important species or cause broad destabilization of the existing biological community.

More information is needed of the composition, structure, and function of the Columbia River ecosystem if we are to make informed decisions and be able to evaluate the consequences of our actions. To gain this information, support should be given to efforts to systematically inventory, classify, and assess ecosystem status and trends. These activities would provide the foundation for a systemwide conservation program: they would make it easier to decide which environmental attributes (processes, linkages, and components) to conserve, provide baseline data for environmental monitoring, help prioritize basic and applied research, and enable better use of sustainable natural resources.

6.1 INVENTORY, CLASSIFICATION, MONITORING, AND EVALUATION

A detailed inventory/survey, classification, and assessment of biological resources (see Boon 1992) should form the backbone of Columbia River fish and wildlife management. A well-designed basinwide inventory would permit refinement of classification techniques, assignment of observed patterns to category or class, and assessment of the quality, quantity, distribution, and pattern of spatial units and biological resources (Table 5).

Surveys should record the relative abundance of species by area, with particular attention paid to threatened, sensitive, or ecologically valuable species; areas that retain historically high levels of biodiversity or endemism; habitats or environments that are critical for the protection of natural and genetic resources; and areas that are threatened by change or destruction. Operationally, the inventory should combine proven sampling methods with new techniques and technologies (e.g., remote sensing, satellite imagery, Geographic Information System mapping and attribute databases) that permit rapid assessment over large areas. Statistical methods should be employed to evaluate sampling effectiveness and to compare the physical and biological characteristics of different areas over time. There needs to be development of standard procedures to collect, store, collate, and disseminate data among user groups. The need for coordination to prevent duplication of effort, to facilitate the exchange of information, and to integrate experimental design and results is paramount.

The physical size and complexity of the Columbia River Basin precludes comprehensive inventory and monitoring, so a means of subsampling representative areas and extrapolating them to unsampled areas would be necessary. Similarly, the diversity of organisms will likely prevent thorough inventory, so surveys should concentrate on subsets of genes, species, species assemblages, and so forth, that can be used as indicators of ecological diversity and status. New techniques and guidelines are needed for measuring, analyzing, and interpreting the effectiveness of reduced datasets in evaluating biodiversity and ecosystem dynamics (e.g., Kremen 1992).

Subsampling and extrapolation require that natural processes, spatial units, and biological components be classified into ecologically meaningful groups or categories. Taxonomic keys and hierarchical watershed classification schemes represent two commonly used approaches to organizing biological and spatial phenomena. It would be desirable to use classification techniques that explicitly incorporate biodiversity data; this would ensure that biodiversity concepts are integrated into monitoring and management programs.

Progress toward environmentally sound management, impact analysis and mitigation, and sustainable resource use requires information on the effects of natural and anthropogenic disturbances on biodiversity. Monitoring refers to measurements that enable accurate assessment of species status and, more generally, the effects of externally-imposed change on ecosystem

Table 5. Potential benefits of a program to inventory, classify, monitor, and evaluate the biological resources of the Columbia River Basin.

Activity	Potential Benefits
Data Acquisition	Species-specific data on life history characteristics, habitat requirements, population dynamics, etc.
	Data sufficient for spatial and temporal trend analyses
	Data for use in process and resource modeling
Planning and Assessment	Reconnaissance and baseline data necessary for further classification and research
	Efficient design and implementation of monitoring through data organization and analysis
	Site-specific information on sensitive areas, project design requirements, enhancement projects, etc.
	Rapid environmental impact assessment, review, and mitigation
	Identification of diversity criteria and thresholds for environmental monitoring and protection
Management	Establishment of conservation and enhancement priorities
	Selection and design of protected areas based on diversity, naturalness, critical species/habitats, etc.
	Coordinated management and more efficient use and of land, water, and biological resources
	Adaptive management and faster response times through constant feedback of information on status of species, habitats, etc.
	Increased accountability through documentation of information sources and decision processes

structure and function, using baseline or control data for comparison. Because monitoring represents an extension of inventory activities over time, the same methods and environmental variables should be employed. Again, the focus should be on devising and applying appropriate measures of diversity at different levels of organization with an eye to management needs.

The commitment to monitoring and evaluation should be long-term and resolute. Monitoring responsibilities should be a recognized component of ecological research and project development programs, especially those likely to have long-term impacts.

Depending on the scale and level of observation, the question of what measurements should be taken to evaluate trends in biodiversity is a crucial one, since considerable effort and expense will be wasted if inappropriate metrics are used. Clearly, criteria should favor readily interpretable (i.e., statistically tractable) data collected from groups (genes, life history types, populations, species, communities) that are amenable to censusing. Better methods and guidelines are needed for choosing good indicator variables for monitoring biotic responses to environmental change. Monitoring data should provide a clear indication of ecosystem condition and health, and establishing conservation priorities, since these are the overriding management objectives.

Larger organisms, including most fish, make good indicators of biodiversity at the community level because they have significant and diverse impacts on other biota, and because they are easy to capture, identify, and enumerate (Moyle and Leidy 1992). Anadromous salmon possess characteristics of all three categories of species that have relevance in resource management: mobile link, indicator, and keystone species (Noss 1990). Mobile link species are species which, through their numerical abundance and ecology, are important functional components within the ecosystem. As indicator species, salmon are sensitive barometers of ecosystem health. They are keystone species because changes in their abundance either directly or indirectly affects the abundance of other species. Finally, some salmon stocks alter the ecological landscape by altering management focus and efforts, regardless of their status as mobile link, indicator, and keystone species. Salmon populations listed under the ESA and those protected by “weak stock” fisheries management are examples of stocks that alter the ecological landscape through their effect on management decisions.

In addition to targeting larger, more readily identifiable organisms, inventory and monitoring within the Columbia River Basin should include other species, especially those that (1) are important regulators of material and energy flow, (2) range over large areas, and/or (3) are vulnerable to perturbation. Monitoring and strategies for conservation should explicitly address the compositional, structural, and functional components biodiversity at genetic through life history, population, species, community, and ecosystem levels of organization (Noss 1990).

6.2 RESEARCH PRIORITIES

One of the major obstacles to devising effective recovery and conservation strategies is a basic lack of knowledge of which environmental components should receive the greater share of our attention, either because they are critical to ecosystem function or are in imminent danger of being lost altogether. The roles, patterns, and effects of shorter (e.g., “reset” events, competiton, predation, disease, bottlenecks, dispersal, recolonization) and longer term (e.g., genetic changes, habitat degradation, global warming) processes on biological diversity need better definition. It is essential that we understand how these processes work in both undisturbed and disturbed settings.

Understanding how aquatic and terrestrial environments are linked together requires a landscape perspective and approach to research. Positive steps have already been taken in this regard. Under Phase III amendments to the Columbia River Basin Fish and Wildlife Program, the Northwest Power Planning Council has called for the establishment of a small number of model watersheds to develop a coordinated and holistic approach to investigating populations, species, and communities in drainages that have been impacted to varying degrees. Research will involve scientists with expertise in large- and small-scale biogeophysical processes. Model, watershed research will be especially valuable as a source of long-term data on natural and man-caused variability in ecosystem structure and function. Long-term research is essential if we are to know what effects our management actions have had.

Even if a determined effort is made to protect critical habitat and to implement other protective measures, it will not necessarily lead to species recovery. The interdependency of knowledge and management makes it unlikely that effective recovery measures can be implemented in the absence of relevant biological information. What is also needed is better knowledge of the adaptive and ecological responses of individuals, populations, and species. Intensive studies are needed to provide guidance in the particular case of listed stocks, and to enable generalizations of wider applicability. Research into life history and population-level variability in physiology, reproduction, behavior, timing, and ecological interactions will enable intelligent management choices and effective monitoring programs.

In the introduction to their book “Research Priorities for Conservation Biology,” Soule and Kohm (1989) noted that conservation goals cannot be met without significant improvements in our understanding of ecosystem dynamics. With some contextual modification, their points bear restating:

1. What types of species and community diversity are critical to the recovery and well-being of listed stocks?

2. What fundamental characteristics of the Columbia River ecosystem are needed to sustain viable populations of listed stocks?

3. How do landscape, river, and reservoir components interact to shape the aquatic community, and the temporal and spatial scales at which regulatory processes operate?

4. What are the consequences of fragmentation?

5. What processes create and maintain stability,resiliency, and diversity at different levels of biological organization?

6. What kinds (e.g., intensity, scale) of disturbance is the system subjected to, and how much can it accommodate before undergoing irreversible change?

7. What are the effects of intentional or inadvertent introductions and removals of hatchery fish and other non-native biota?

8. Can we improve our ability to anticipate the effects of man's activities and to integrate "unnatural" events and processes into more-natural ecosystem dynamics?

9. Can damaged ecosystems be restored to encourage recovery of depressed stocks, regain ecological equilibrium, and minimize future human impacts?

6.3 MANAGINGBIODIVERSITY

If such is the goal, there are essentially three strategies for enhancing biodiversity within the Columbia River Basin. One is to purposefully manipulate the genetic resources of resident biota through artificial selection, infusions of new genetic material, and selective breeding. This general approach has been proposed as a means of restoring lost genetic diversity among captive fish populations (Moyle and Sato 1991), but is generally viewed as having unacceptable risks (Kapuscinski and Miller 1992). To place these risks in perspective, one needs to differentiate between counter-selection to 'undo evils done' (Kapuscinski and Miller 1992), intentional selection for desired traits, and the introduction of new genetic material through selective outbreeding, mutation, genetic engineering, or some other genetic transferral technique. Only the latter approach offers opportunities for increasing genetic diversity but, like counter- and intentional selection, may actually reduce the overall fitness of the natural population.

Rather than attempt to directly alter genetic patterns, it may be better to maintain a variety of natural habitats of high quality, and allow natural selection to restore genetic diversity (see below; Kapuscinski and Philipp 1987).

A second approach to increasing biodiversity is to alter community structure through the intentional introduction and removal of organisms. The abundance of certain species, notably fish, can be controlled through harvest and other depletion activities. Controls on fishing typically involve regulating the number of fishermen, their access to fish, and the number of fish that they can catch. An important consideration is the selective pressures imposed by the fishery and their potential effects on genetic resources (Ricker 1981). Fishing should be managed to minimize selection differentials and thereby maintain naturally occuring phenotypic and genetic diversity.

In addition to exploitation, other forms of control include removals of undesirable species and the introduction or supplementation of desirable species. Entire fish assemblages can be eliminated through the use of piscicides, but this approach has limited applicability in larger areas of the Columbia River. Selective harvest has been used in an attempt to control squawfish populations in Snake and Columbia river reservoirs (Willis and Nigro 1991). The justification for reducing the abundance of unwanted species like the squawfish is to disrupt competition and predator-prey interactions so that other species can increase in abundance or persist where they may not have otherwise.

Stocking is the primary means whereby new fish species may be introduced, native species reintroduced, and losses to fishing and other causes of mortality offset. Virtually all of the stocking activities in the Columbia River system have involved hatchery-reared salmon and trout. The stocking of salmon has produced mixed results -- generally successful in terms of increasing fishing opportunities and establishing populations where none previously existed, but notably unsuccessful when the goal has been to enhance the natural production of existing stocks (Miller et al. 1990). In some cases, uncritical stocking and supplementation have had undesirable genetic, species, and community-level effects. Failed attempts at supplementation have been blamed on a lack of knowledge of the ecology of the target organism and associated biota (Steward and Bjomn 1990). Nevertheless, artificial propagation in general and supplementation in particular hold considerable promise as recovery and enhancement tools (Lichatowich and Watson 1993). The development of successful supplementation techniques is essential to recovery efforts given the higher levels of exploitation and habitat degradation expected in the future.

A third approach to conserving biodiversity is to increase the quality and complexity of the aquatic ecosystem through the conservation of desirable environmental characteristics, through the restoration of damaged habitat, and through the intentional manipulation of key environmental variables (Petts et al. 1989). Within the Columbia River, the manipulation of flow, water temperature, reservoir water surface elevations, and dam operations have potential as tools to facilitate the migration and increase the survival of salmon smolts and returning adults. The Fish and Wildlife Program established an annual “Water Budget” volume of 1.19 million acre feet (maf) for the Snake River, and 3.45 maf for the Columbia River for use during the spring migration of juvenile salmon and steelhead (NPPC 1986). Various flow augmentation and reservoir drawdown scenarios are being contemplated as recovery measures (USACE et al. 1992; Giorgi 1993). Some of these activities may be detrimental to non-target populations. For example, water released under the Water Budget may not benefit all populations or species of anadromous fish equally. Reservoir drawdowns may very well increase the travel speed and survival of smolts, but they also strand resident fish and invertebrates, inhibit the spawning of other species, and displace fish downstream (USACE 1992). Flow, water quality, and reservoir management should be examined in light of their overall impact on resident biota.

Certain types of river regulation - structural modifications and special operational rules for water storage and hydroelectric projects - can be used to achieve beneficial effects in terms of biodiversity. Management practices that simulate natural disturbances in scale, frequency, intensity, and seasonality are more likely to maintain biological diversity and function than are actions that result in artificial conditions (Petts et al. 1989). Regulation can also mitigate or buffer extreme environmental events so that habitat and community structure are preserved. The exact measures employed will depend on the desired ecological endpoint (i.e., historical, existing, or some future conditions).

6.4 CRITICAL HABITAT AND PROTECIED AREAS

Species recovery and the conservation of biodiversity begins with the identification of critical habitats, and steps taken to rehabilitate, enhance, and protect these areas. The creation and management of ecological preserves has long been recognized as a basic tool for conserving terrestrial ecosystems (National Academy of Sciences 1992); only recently have preserves been set aside specifically to protect aquatic resources (Williams 1991). Moyle and Sato (1991) provide justification for the establishment of an aquatic preserve system in the western United States, along with methods for classifying and assessing areas having different conservation value. Interestingly, they identify museum specimens, because they serve as repositories of genetic material, as a class worth preserving on their own!

Williams (1991) distinguishes between refuges (areas managed for one or a few species) and preserves (community rather than species-oriented). He recognizes the short-term utility of refuges to assist in the recovery of threatened and endangered species but indicates a preference for relying on preserves to protect remaining areas of high diversity. Moyle and Sato (1991) argue that aquatic conservation management should favor a combination of many smaller preserves encompassing unique habitats and a few large preserves of high ecological diversity. Criteria for assessing the conservation value of natural areas as preserves include size, ecological diversity, naturalness, representativeness, rarity, fragility, potential value, intrinsic appeal, recorded history, and threat of human interference (Ratcliffe 1977, Boon 1992). Of these, diversity, naturalness, and representativeness should perhaps be given greater weight. Moyle and Sato (1991) offered several guidelines (paraphrased below) for selecting large natural areas as preserves. To be considered, an area must:

1. contain resources and habitat conditions necessary for the persistence of resident biota;

2. be large enough to allow for the range and variability in conditions needed to maintain natural species diversity and ecosystem function;

3. be protected from edge and external effects in order to maintain good internal quality;

4. contain enough within-boundary replication of different-sized spatial. units dispersed over a large enough area to avoid problems created by local extirpations; and

5. be able to support populations large enough to be self-sustaining in the face of demographic or genetic stochasticity.

There is general agreement among conservation biologists of the need to establish preserves in areas that contain most of their original biota, in as many regions as possible (Sheldon 1988, Williams 1991). Moyle and Leidy (1992) recommended focusing on “big-river specialists” on a species-by-species basis while attempting preserve-level protection for tributary communities. For the Columbia River, the most practical approach may be to combine a variety of pristine and semi-natural areas into a system-wide network that maintains a diversity of stable and representative biological communities. Different conservation, enhancement, and resource utilization strategies can be applied to different areas depending on local management objectives to achieve an economically and ecologically acceptable mix of habitats and species.

Another important step in species recovery and Columbia River management is the restoration of habitats and ecosystems that have either been lost or reduced in quality. By restoration is meant the re-creation of entire, balanced communities of organisms, modelled on pristine or semi-pristine states, yet allowing for human uses. Effective implementation will require the development of a long-term, integrated plan that identifies opportunities and strategies for restoring desired ecological attributes at scales ranging from local to landscape.

7. PERSPECTIVES FOR THE FUTURE

Our central thesis is that species recovery options should be considered within the larger context of maintaining biological variety and variability across all scales and levels of organization. The best way to maintain biodiversity and ensure the survival and adaptive potential of individual species is to conserve entire, naturally functioning communities and associated habitats. Protection should be extended to both aquatic and terrestrial ecosystems within the Basin. So that we may know what to conserve, and to establish a scientific basis for doing so, we must begin a program to classify, inventory, and assess the river's natural resources. We need to fund basic research into the ecological requirements of riverine biota and the natural processes that sustain them. We need to develop better procedures for environmental inventory and assessment. Using this information, managers can set policies, communicate them to the public, and see that they are carried out. We should use whatever means are available to us to create, as best we can, conditions that maintain biodiversity and other desirable environmental attributes. Consideration should be given to developing a basin-wide preserve system wherein management objectives are tailored to local conditions. To evaluate the effectiveness of our actions along with future environmental impacts, there needs to be a strong commitment to long-term monitoring, evaluation, and adaptive management.

Management reform that aims to protect ecosystems and not just species will be limited by a variety of economic, bureaucratic, and political constraints. These constraints will change as public awareness mounts of the local, regional, and global costs of environmental neglect and lost biodiversity. As leaders of the recovery effort, Recovery Team members are in a unique position to influence public opinion through the judicious application of scientific knowledge. Although recovery plans should be supported by the best available data, they should not take too narrow a focus. The proper perspective is implicit within the language of the Endangered Species Act itself, namely "to provide a means whereby the ecosystems upon which endangered species and threatened species depend, may be conserved." Conservation of ecosystems and associated biological communities will not only enhance the odds for salmon recovery, but will increase the probability that salmon and other species will avoid extinction in the future,

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